

# Impact of Desert Urbanization on Urban Heat Islands Effect

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## Abstract

The United Arab Emirates (UAE) has undergone major urban transformation after the establishment of the country in 1971. One noticeable change is urban expansion in terms of massive infrastructure, including new residential areas, highways, airports, and sophisticated transportation systems. Major landscape changes and disturbances, such as urban development, are among the major contributors to global climate change. Urban areas can be 3.5°C - 4.5°C warmer than neighboring rural areas, a phenomenon known as urban heat islands (UHIs). As such, urban development in the UAE was expected to follow a similar pattern and to be a major contributor to the country's impact on global climate change. Analyses of multi-temporal (1988-2017) land surface temperature (LST) data obtained from Landsat satellite datasets over a desert city in the UAE showed unexpected results. Urbanization of desert surfaces in the study area led to a decrease of 3°C - 5°C in the overall LST. This was attributed to the associated expansion of green spaces in the newly developed urban areas, the expansion of date plantations and perhaps a cooling in the previously desert surface. Therefore, the UHI effect was not well demonstrated in the studied desert surfaces converted to urban areas.

## Keywords

Land Surface Temperature, Thermal Difference, UAE, Urbanization, Urban Heat Islands

## 1. Introduction

Knowledge of land surface temperature aids understanding of the temporal and spatial variations in global land surfaces [1]. This is because LST and emissivity

are vital parameters in earth surface characteristics for energy budget estimation and land cover assessment [2]. LST data are typically retrieved from raw Landsat datasets by converting the digital number values of the thermal bands into absolute radiance values [3] [4]. These radiance values are then used to find satellite brightness temperatures, calculated under the assumption of unity emissivity and using pre-launch calibration constants [3] [4] [5]. Emissivity-based methods have been applied to urban areas [6] and vegetation cover-based methods to agricultural areas [7]. Current understanding of spatial thermal patterns and their association with surface characteristics is based on numerous studies of urban surface temperatures over the past two decades [8]. Based on [9], urban areas are generally 3.5°C - 4.5°C warmer than surrounding rural areas. [10] projected that more than 5.87 million km<sup>2</sup> of land globally will probably be converted into urban areas by 2030, and 20% of this area has a probability of less than 75% of further urban expansion. [8] used detailed land-cover maps with reasonably similar surfaces to help in measuring temperature gradients across a region. This is because surface temperature is uniquely related to surface properties. Estimating thermal conditions of land surface using satellite images requires the relationship between surface temperature, surrounding topography, and land use and land cover to be determined [4] [11].

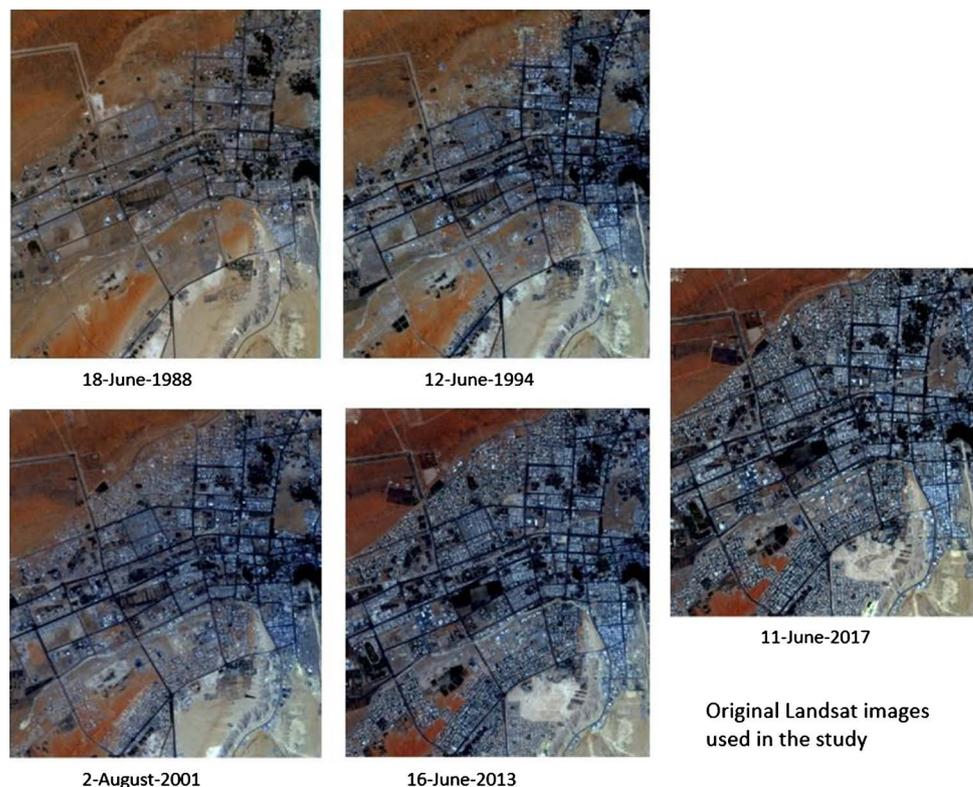
Cities experience direct environmental impacts, such as uneven effects from temperature increases, variations in glacial melt, and sea-level rise. Possible future increases in temperature are expected to worsen the urban heat island (UHI) effects [12], where cities become warmer than their surrounding area [13] [14]. This warming is of particular concern for urban areas due to the UHI effects [15]. The UHI effect results from the retention of solar energy in building materials during the day and lower rates of radiant cooling at night. Urban areas commonly experience lower wind speeds, less convective heat loss and evapotranspiration, and more energy from surface warming [16]. As a product of urbanization and industrialization, UHI is believed to be one of the main dilemmas of the century [17]. Rapid urbanization imposes dramatic land surface alteration and replacement of natural landscapes, which can significantly change the surface radiation, thermal properties, and humidity [18] [19]. Transformation of natural land cover and the need for urban materials lead to climatic changes [11].

According to [8], the UHI effect occurs when land cover is transformed, mostly via the replacement of natural vegetation and agricultural land by concrete, asphalt, and building walls related to urban land uses. Extreme heat in cities is constantly generated and released into the atmosphere by building infrastructure and transportation [20]. Urban areas have consequently become vital drivers of local and regional climatic and environmental changes, with harmful consequences for social and ecological processes [21]. Commercial and residential buildings, roads, and parking lots covered by impervious surfaces worsen the UHI effect, whereas vegetation, such as trees, grass, and shrubs, can alleviate it

[22]. In the past few decades, the land use land cover (LULC) of the UAE has significantly changed. Where the vegetation has increased and the built up areas have expanded [23]. [24] found that large parks in Dubai City had significantly lower temperatures than the rest of the city during summer. Increasing the proportion of green spaces, such as public parks, gardens, trees, and green roofs, is an effective strategy for urban areas to adapt both climate change and the UHI [25] [22] [26]. The preliminary hypothesis of this study is that urban centers would portray higher temperature levels than the surrounding desert surface. The objective is to detect and study the change in LST with respect to the change in Land cover in the past 30 years in Al-Ain City.

## 2. Study Area and Satellite Data

Al-Ain City is located in the eastern part of the Emirate of Abu Dhabi, United Arab Emirates (UAE). The area is characterized by an arid climate of extremely hot summers and warm winters, with an average annual temperature of 27°C and a mean annual rainfall of 96.4 mm [27]. The city is considered one of the largest oases in the Arabian Peninsula. The study area covered the airport area in the northwest, Buraimi border (Oman) in the northeast, central district in the east, Sanaeya industrial area in the southeast, Maqam in the west, and Jabal Ha-feet and cement factory in the south. The central residential area includes some palm plantation farms and parks (see **Figure 1**). Landsat images captured during



**Figure 1.** Landsat false color images of the study area in Al-Ain City, United Arab Emirates taken from original Landsat images.

the summer (June 18, 1988; June 12, 1994; August 2, 2001; June 16, 2013; and June 11, 2017) (<http://earthexplorer.usgs.gov/>) were used in this study (Table 1). Images were selected during the summer to portray the peak LST of the study area.

### 3. Methodology

The image processing workflow shown in Figure 2 was followed:

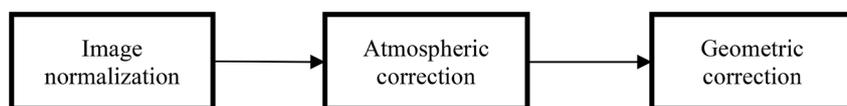
1) Image normalization was applied to eliminate the effect of different sensors and dates. The image normalization techniques developed by [28] were used to reduce artificial LST changes introduced by sensor technology, illumination, and viewing geometry changes on the thermal bands of the images.

2) Using the equation  $(mb1 + b)$ .  $m = (Br Dr)/(Bs Ds)$ ,  $b = (Dr \times Bs) (Ds \times Br)/(Bs Ds)$ ,  $b1$  is the thermal band of the sub image,  $Br$  is the mean temperature of the bright pixels of the reference image,  $Dr$  is the mean temperature of the dark pixels of the reference image,  $Bs$  is the mean temperature of the bright pixels of the sub image,  $Ds$  is the mean temperature of the dark pixels of the sub image. Corrected values are shown in Table 2.

Atmospheric correction and LST retrieval was done. LST retrieval from satellite data is considered an important but challenging topic in thermal studies of urban environments [29]. A single-channel algorithm developed by [30] was employed, which includes an updated fit using MODTRAN4 radiative transfer code [31]. This algorithm has proven its effectiveness for Landsat 8 thermal

**Table 1.** Details of Landsat images used in the study.

	Path	Row	Date	Time
Landsat 1 - 5	160	43	11-06-1988	6:17:06
Landsat 4 - 5	160	43	12-06-1994	6:05:33
Landsat 4 - 5	160	43	02-08-2001	6:26:53
Landsat 8	160	43	16-06-2013	6:48:32
Landsat 8	160	43	11-06-2017	6:46:15



**Figure 2.** Image processing workflow followed in this study.

**Table 2.** Al-Ain City normalization equation variables.

	AA 94	AA 2001	AA 2013	AA 2017
Bs	321.23	322.11	328.03	333.168
Ds	311.78	309.44	307.99	311.09
M	1.614	1.204	0.761	0.691
B	-187.457	-56.685	81.482	100.989

infrared sensors (band 10) [32]. In this algorithm, the emissivity effects were corrected using an approach developed by [33]. LST values were then converted from Kelvin to degrees Celsius. **Table 3** shows the corrected mean temperatures.

3) Image warping was performed to locate and match the tie points in a base and warp image to ensure that they were in the same location that was changed after normalization. The thermal differences are shown in **Figure 3**.

4) Raster color slicing was applied by setting the temperature change value based on multiple trails and chose the most likely proper values for each difference image. Blue color indicates the cooler areas and red indicate the warmer areas (**Figure 4**).

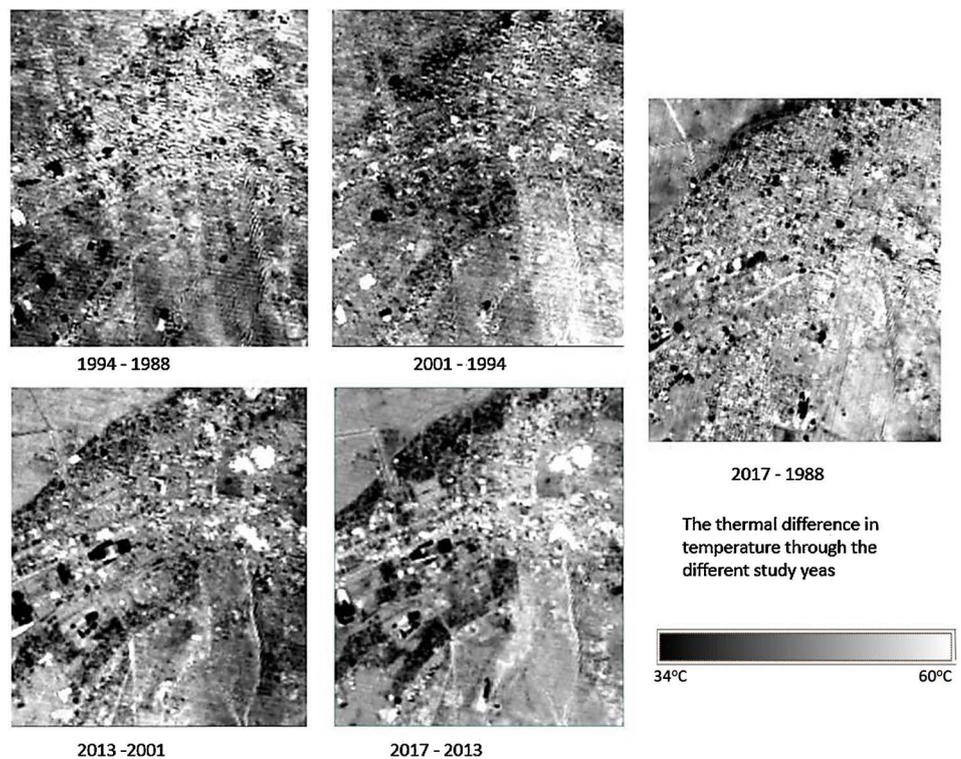
5) The green space areas in km<sup>2</sup> of the study area was found using NDVI by applying the equation  $(NIR - R)/(NIR + R)$ , taking into consideration that for images taking from Landsat 4 - 7, NIR is band 4 and R is band 3 while in Landsat 8 the NIR is band 5 and R is band 5 (see **Table 4**).

### 4. Results and Discussion

Land cover areas were manually identified in the thermal images based on our

**Table 3.** Al-Ain City corrected mean temperatures in study period.

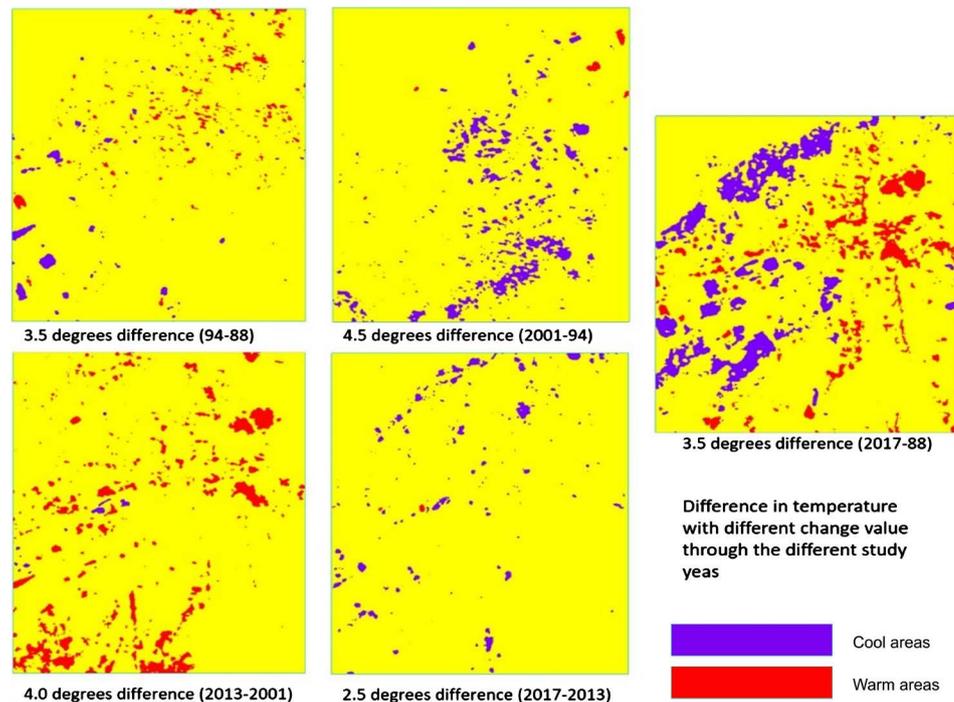
Temp	1988	1994	2001	2013	2017
K	326.52	325.59	325.68	328.07	327.83
°C	53.37	52.44	52.53	54.92	54.68



**Figure 3.** Thermal difference images of Al-Ain City throughout the study period.

**Table 4.** Green spaces in the study area.

Year	Area (km <sup>2</sup> )
1988	2.4
1994	3.3
2001	1.1
2013	8.7
2017	13.53

**Figure 4.** Difference in land surface temperature in Al-Ain City throughout the study period.

knowledge of the area and available land use and land cover maps from AL Ain city Municipality. Our results showed that, the mean LST in Al-Ain city has increased by 1.31°C from 53.37°C in 1988 to 54.68°C in 2017. The difference in LST from 1988 to 2017 was 3.5 degrees the largest difference is from 2001 to 1994 by 4.5 degrees (**Figure 4**). **Table 5** shows the changes in mean temperature in four areas in Al-Ain City, namely the airport area, Falaj Hazzaa, Sanaeya industrial area, and Maqam rugby club.

The temperature in the airport area decreased by 3.49°C from 1988 to 2017. In Falaj Hazzaa, the temperature decreased by 5.1°C between 2017 and 1988. In contrast, the temperature in Sanaeya has increased by 4°C since 1988. The temperature in the rugby club area decreased by 4.39°C during the study period. It was noticed that the green space in the study area over the study period decreased in 2001, was 3.3 km<sup>2</sup> in 1994 and dropped to 1.1 km<sup>2</sup> in 2001 (**Table 4**).

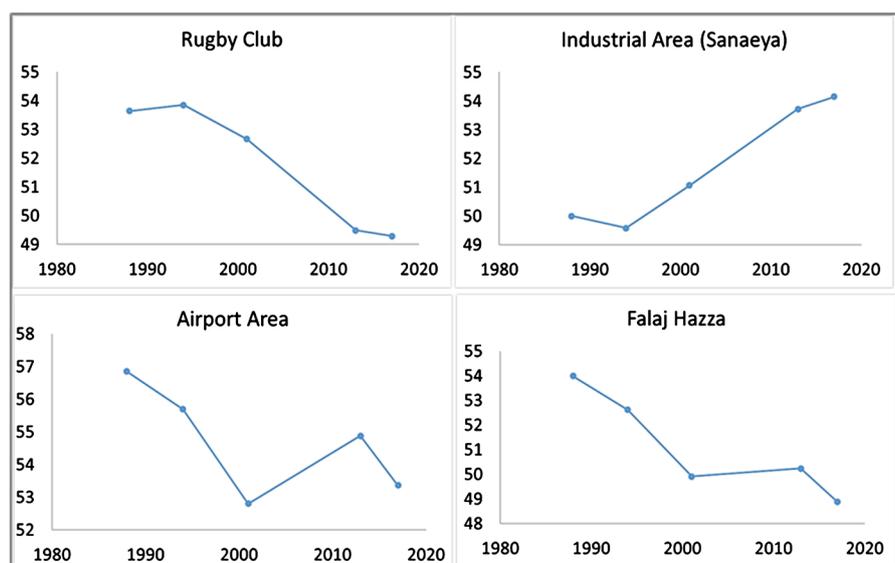
[34], reported that the hottest urban surfaces are paved areas during both day and night because of their high thermal inertia, which allows them to absorb and

store more sunlight. In addition to the presence of factories, metal workshops, and other related services in the industrial area (Sanaeya), the high density and high traffic as well as the absence of plantations and green areas, Sanaeya experienced increased temperature compared to other areas in Al-Ain. The rugby club in Maqam was established in 2007, and the plot was previously bare land. Changes in temperature could have been due to the vegetation cover in the rugby course and surrounding urbanized areas. **Figure 5** shows the temperature trends in Al-Ain City.

In a study by [35] on Abu Dhabi city, they found that in desert area the UHI phenomenon is commonly inverted because of the high amount of vegetation in urban areas compared to suburban areas where bare ground and sand are found. They also reported that, during the night, the temperature of the different surfaces drops and the suburbs become cooler compared to downtown areas; consequently, the typical UHI effect can be detected only at night [35]. According to [36], commonly the UHI effect makes the city center warmer than the surrounding areas. Yet this phenomenon is inverted in desert environments. This inversion is due to the vegetation found in urban areas with comparison to suburban areas, where bare lands and hot sand dunes are spreading. [36]' results showed that the UHI has been affected by the change in vegetation fraction and a negative relationship between vegetation fraction and temperature was reported.

**Table 5.** Mean land surface temperature change ( $^{\circ}\text{C}$ ) found in Al-Ain City.

Year	Airport	Falaj Hazzaa	Sanaeya	Rugby club
1988	56.85	53.99	50.00	53.64
1994	55.69	52.61	49.58	53.85
2001	52.80	49.91	51.06	52.66
2013	54.88	50.24	53.72	49.49



**Figure 5.** Temperature trends in degree Celsius over the study period in Al-Ain City.

The findings of [37] study on Dubai City, showed that LST has greatly reduced because of the increase in urban vegetation cover. In this study the difference in LST from 1988 to 2017 was 3.5 degrees the largest difference is from 2001 to 1994 by 4.5 degrees. This period experienced a drop in the green area which can explain the big variance in LST. The seasonal variation can be noticed clearly in downtown vegetated areas. Vegetation is stressed due to high temperatures in summer months, accordingly NDVI values drop [38]. In this study, the green space in the study area over the study period decreased in 2001 (Table 4). This decrease can be due to seasonal changes. The 2001 image was taken in August, whereas the other images were taken in June. It was not possible to use an image of June 2001 because of the defects in the images from that month. The findings of a study by [29] on Dubai showed that LST decreases when the urban areas are planted and the amount of green space influences the urban areas. In exception of the decrease in 2001, the green area was increasing with time which can explain the decrease in LST.

## 5. Conclusion

Urbanization is generally thought to lead to the replacement of natural landscapes, resulting in changes in surface radiation, thermal properties, and humidity. Urban areas can be 3.5°C - 4.5°C warmer than neighboring rural areas due to the UHI effect. Contrary to previous studies, urbanization of desert surfaces in this study did not show a pronounced UHI effect. Generally, a decrease in LST was observed rather than an increase in the studied urban areas compared to surrounding desert surfaces. LST decreased by 3.49 in the airport area and 5.1°C in Falaj Hazzaa from 1988 to 2017. Green areas, such as the rugby club, also experienced a temperature decrease of 4.39°C over the study period. In contrast, Sanaeya industrial area has experienced an increased LST of about 4°C since 1988. The overall decrease was likely primarily due to a significant increase in urban vegetation, such as trees, public parks, and lawns in residential areas. The Sanaeya industrial area showed a classical UHI due to the absence of such urban vegetation

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

- [1] Li, Z.-L., Tang, B.-H., Wu, H., Ren, H., Yan, G., Wan, Z., Trigo, I.F. and Sobrino, J.A. (2013) Satellite-Derived Land Surface Temperature: Current Status and Pers-

- pectives. *Remote Sensing of Environment*, **131**, 14-37.  
<https://doi.org/10.1016/j.rse.2012.12.008>
- [2] Srivastava, P., Majumdar, T. and Bhattacharya, A.K. (2010) Study of Land Surface Temperature and Spectral Emissivity Using Multi-Sensor Satellite Data. *Journal of Earth System Science*, **119**, 67-74. <https://doi.org/10.1007/s12040-010-0002-0>
- [3] Chander, G., Markham, B.L. and Helder, D.L. (2009) Summary of Current Radiometric Calibration Coefficients for Landsat mss, tm, etm+, and eo-1 Ali Sensors. *Remote Sensing of Environment*, **113**, 893-903.  
<https://doi.org/10.1016/j.rse.2009.01.007>
- [4] Weng, Q. (2009) Thermal Infrared Remote Sensing for Urban Climate and Environmental Studies: Methods, Applications, and Trends. *ISPRS Journal of Photogrammetry and Remote Sensing*, **64**, 335-344.  
<https://doi.org/10.1016/j.isprsjprs.2009.03.007>
- [5] Estoque, R.C., Murayama, Y. and Myint, S.W. (2017) Effects of Landscape Composition and Pattern on Land Surface Temperature: An Urban Heat Island Study in the Megacities of Southeast Asia. *Science of the Total Environment*, **577**, 349-359.  
<https://doi.org/10.1016/j.scitotenv.2016.10.195>
- [6] Nichol, J. (2009) An Emissivity Modulation Method for Spatial Enhancement of Thermal Satellite Images in Urban Heat Island Analysis. *Photogrammetric Engineering & Remote Sensing*, **75**, 547-556. <https://doi.org/10.14358/PERS.75.5.547>
- [7] Merlin, O., Duchemin, B., Hagolle, O., Jacob, F., Coudert, B., Chehbouni, G., Dedieu, G., Garatuza, J. and Kerr, Y. (2010) Disaggregation of Modis Surface Temperature over an Agricultural Area Using a Time Series of Formosat-2 Images. *Remote Sensing of Environment*, **114**, 2500-2512. <https://doi.org/10.1016/j.rse.2010.05.025>
- [8] Buyantuyev, A. and Wu, J. (2010) Urban Heat Islands and Landscape Heterogeneity: Linking Spatiotemporal Variations in Surface Temperatures to Land-Cover and Socioeconomic Patterns. *Landscape Ecology*, **25**, 17-33.  
<https://doi.org/10.1007/s10980-009-9402-4>
- [9] Zhang, X., Estoque, R.C. and Murayama, Y. (2017) An Urban Heat Island Study in Nanchang City, China Based on Land Surface Temperature and Social-Ecological Variables. *Sustainable Cities and Society*, **32**, 557-568.  
<https://doi.org/10.1016/j.scs.2017.05.005>
- [10] Seto, K.C., Guneralp, B. and Hutyrá, L.R. (2012) Global Forecasts of Urban Expansion to 2030 and Direct Impacts on Biodiversity and Carbon Pools. *Proceedings of the National Academy of Sciences*, **109**, 16083-16088.  
<https://doi.org/10.1073/pnas.1211658109>
- [11] Muthamilselvan, A., Srimadhi, K., Ramalingam, N. and Pavithra, P. (2016) Urbanization and Its Related Environmental Problem in Srirangam Island, Tiruchirappalli District of Tamil Nadu, India-Thermal Remote Sensing and GIS Approach. *Environmental Earth Sciences*, **75**, 765. <https://doi.org/10.1007/s12665-016-5457-0>
- [12] Corburn, J. (2009) Cities, Climate Change and Urban Heat Island Mitigation: Localising Global Environmental Science. *Urban Studies*, **46**, 413-427.  
<https://doi.org/10.1177/0042098008099361>
- [13] Choudhary, B.K., Tripathi, A.K. and Rai, J. (2019) Can Poorcities Breathe: Responses to Climate Change in Low-Income Countries. *Urban Climate*, **27**, 403-411.  
<https://doi.org/10.1016/j.uclim.2019.01.001>
- [14] Stewart, I.D. and Oke, T.R. (2012) Local Climate Zones for Urban Temperature Studies. *Bulletin of the American Meteorological Society*, **93**, 1879-1900.  
<https://doi.org/10.1175/BAMS-D-11-00019.1>

- [15] Skelhorn, C.P., Levermore, G. and Lindley, S.J. (2016) Impacts on Cooling Energy Consumption Due to the Uhi and Vegetation Changes in Manchester, UK. *Energy and Buildings*, **122**, 150-159. <https://doi.org/10.1016/j.enbuild.2016.01.035>
- [16] Wilby, R.L. (2007) A Review of Climate Change Impacts on the Built Environment. *Built Environment*, **33**, 31-45. <https://doi.org/10.2148/benv.33.1.31>
- [17] Shen, H., Huang, L., Zhang, L., Wu, P. and Zeng, C. (2016) Long-Term and Fine-Scale Satellite Monitoring of the Urban Heat Island Effect by the Fusion of Multitemporal and Multi-Sensor Remote Sensed Data: A 26-Year Case Study of the City of Wuhan in China. *Remote Sensing of Environment*, **172**, 109-125. <https://doi.org/10.1016/j.rse.2015.11.005>
- [18] Liu, H., Zhan, Q., Yang, C. and Wang, J. (2019) The Multi-Timescale Temporal Patterns and Dynamics of Land Surface Temperature Using Ensemble Empirical Mode Decomposition. *Science of the Total Environment*, **652**, 243-255. <https://doi.org/10.1016/j.scitotenv.2018.10.252>
- [19] Wang, K., Wang, J., Wang, P., Sparrow, M., Yang, J. and Chen, H. (2007) Influences of Urbanization on Surface Characteristics as Derived from the Moderate-Resolution Imaging Spectroradiometer: A Case Study for the Beijing Metropolitan Area. *Journal of Geophysical Research: Atmospheres*, **112**, D22S06. <https://doi.org/10.1029/2006JD007997>
- [20] Bonan, G. (2015) *Ecological Climatology: Concepts and Applications*. Cambridge University Press, Cambridge. <https://doi.org/10.1017/CBO9781107339200>
- [21] Wu, J. (2008) Toward a Landscape Ecology of Cities: Beyond Buildings, Trees, and Urban Forests. In: *Ecology, Planning, and Management of Urban Forests*, Springer, Berlin, 10-28. [https://doi.org/10.1007/978-0-387-71425-7\\_2](https://doi.org/10.1007/978-0-387-71425-7_2)
- [22] Cao, X., Onishi, A., Chen, J. and Imura, H. (2010) Quantifying the Cool Island Intensity of Urban Parks Using Aster and Ikonos Data. *Landscape and Urban Planning*, **96**, 224-231. <https://doi.org/10.1016/j.landurbplan.2010.03.008>
- [23] Hussein, K., Alkaabi, K., Ghebreyesus, D., Liaqat, M.U. and Sharif, H.O. (2020) Land Use/Land Cover Change along the Eastern Coast of the UAE and Its Impact on Flooding Risk. *Geomatics, Natural Hazards and Risk*, **11**, 112-130. <https://doi.org/10.1080/19475705.2019.1707718>
- [24] Al-Yaqoob, D. (2012) Simulation Study of Thermal Effects of Vegetation Covered Sand Dune Mounds within the Landscape around Urban Structures in the UAE. PhD Thesis, The British University, Dubai.
- [25] Bowler, D.E., Buyung-Ali, L., Knight, T.M. and Pullin, A.S. (2010) Urban Greening to Cool Towns and Cities: A Systematic Review of the Empirical Evidence. *Landscape and Urban Planning*, **97**, 147-155. <https://doi.org/10.1016/j.landurbplan.2010.05.006>
- [26] Noro, M. and Lazzarin, R. (2015) Urban Heat Island in Padua, Italy: Simulation Analysis and Mitigation Strategies. *Urban Climate*, **14**, 187-196. <https://doi.org/10.1016/j.uclim.2015.04.004>
- [27] Jorgensen, D.G. and Al Tikiriti, W.Y. (2003) A Hydrologic and Archeologic Study of Climate Change in Al Ain, United Arab Emirates. *Global and Planetary Change*, **35**, 37-49. [https://doi.org/10.1016/S0921-8181\(02\)00090-5](https://doi.org/10.1016/S0921-8181(02)00090-5)
- [28] Hall, F., Strebel, D., Nickeson, J. and Goetz, S. (1991) Radiometric Rectification: Toward a Common Radiometric Response among Multidate, Multisensor Images. *Remote Sensing of Environment*, **35**, 11-27. [https://doi.org/10.1016/0034-4257\(91\)90062-B](https://doi.org/10.1016/0034-4257(91)90062-B)

- [29] Nassar, A.K., Blackburn, G.A. and Whyatt, J.D. (2017) What Controls the Magnitude of the Daytime Heat Sink in a Desert City? *Applied Geography*, **80**, 1-14. <https://doi.org/10.1016/j.apgeog.2017.01.003>
- [30] Jimenez-Munoz, J.C., Cristobal, J., Sobrino, J.A., Soria, G., Ninyerola, M. and Pons, X. (2009) Revision of the Single-Channel Algorithm for Land Surface Temperature Retrieval from Landsat Thermal-Infrared Data. *IEEE Transactions on Geoscience and Remote Sensing*, **47**, 339-349. <https://doi.org/10.1109/TGRS.2008.2007125>
- [31] Staenz, K., Secker, J., Gao, B.-C., Davis, C. and Nadeau, C. (2002) Radiative Transfer Codes Applied to Hyperspectral Data for the Retrieval of Surface Reflectance. *ISPRS Journal of Photogrammetry and Remote Sensing*, **57**, 194-203. [https://doi.org/10.1016/S0924-2716\(02\)00121-1](https://doi.org/10.1016/S0924-2716(02)00121-1)
- [32] Jimenez-Munoz, J.C., Sobrino, J.A., Skokovic, D., Mattar, C. and Cristobal, J. (2014) Land Surface Temperature Retrieval Methods from Landsat-8 Thermal Infrared Sensor Data. *IEEE Geoscience and Remote Sensing Letters*, **11**, 1840-1843. <https://doi.org/10.1109/LGRS.2014.2312032>
- [33] Snyder, W.C., Wan, Z., Zhang, Y. and Feng, Y.-Z. (1998) Classification-Based Emissivity for Land Surface Temperature Measurement from Space. *International Journal of Remote Sensing*, **19**, 2753-2774. <https://doi.org/10.1080/014311698214497>
- [34] Taha, H. (1997) Urban Climates and Heat Islands: Albedo, Evapotranspiration, and Anthropogenic Heat. *Energy and Buildings*, **25**, 99-103. [https://doi.org/10.1016/S0378-7788\(96\)00999-1](https://doi.org/10.1016/S0378-7788(96)00999-1)
- [35] Lazzarini, M., Marpu, P.R. and Ghedira, H. (2013) Temperature-Land Cover Interactions: The Inversion of Urban Heat Island Phenomenon in Desert City Areas. *Remote Sensing of Environment*, **130**, 136-152. <https://doi.org/10.1016/j.rse.2012.11.007>
- [36] Issa, S. and Saleous, N. (2014) Satellite Image-Based Analysis of the Greening Impact on the Formation of an Urban Heat Island (UHI) in Abu Dhabi City. *The Arab World Geographer*, **17**, 91-101.
- [37] Abdi, A.M. (2019) Decadal Land-Use/Land-Cover and Land Surface Temperature Change in Dubai and Implications on the Urban Heat Island Effect: A Preliminary Assessment. <https://doi.org/10.31223/osf.io/w79ea>
- [38] Julien, Y., Sobrino, J.A., Mattar, C., Ruescas, A.B., Jimenez-Munoz, J.C., Soria, G., Hidalgo, V., Atitar, M., Franch, B., Cuenca, J. (2011) Temporal Analysis of Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) Parameters to Detect Changes in the Iberian Land Cover between 1981 and 2001. *International Journal of Remote Sensing*, **32**, 2057-2068. <https://doi.org/10.1080/01431161003762363>